BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Lunar Surface Mobility Systems for Lunar Exploration - Case 232

DATE: July 10, 1967

FROM: R. Sehgal

MEMORANDUM FOR FILE

I. INTRODUCTION

The lunar surface mobility systems as presently conceived basically consist of:

A. The Extravehicular Mobility Unit, which will provide the only means of protection and survival for the astronaut during lunar excursions. For the early Apollo missions the excursions on foot will be the only form of surface exploration and will be limited to a very short distance from the spacecraft.

B. The Lunar Scientific Survey Module, which is planned for the post-Apollo period and will provide a means of surface transportation with a 1,000 pound gross payload capability to a range of approximately 8 km.

C. The Lunar Flying Vehicle, which is presently being studied, and may have a varying payload capability depending on whether a one or two man vehicle is used, amount of fuel available, refueling capabilities, number of sorties to be flown and overall mission objectives.

The objective of this memorandum is to briefly discuss these mobility systems, their capabilities and limitations for the manned lunar exploration program.

II. DISCUSSION

Extravehicular Mobility Unit (EMU)*

The Extravehicular Mobility Unit, which has its own communications, electrical power, and environment control, consists of the following major sub-assemblies.(1)

1. Portable Life Support System
2. Pressure Garment Assembly

[redacted]

*EMU is continuously being improved and uprated.

(NASA-CR-88722) LUNAR SURFACE MOBILITY SYSTEMS FOR LUNAR EXPLORATION (Bellcomm, Inc.) 15 p

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ABSTRACT

Three forms of mobility systems for the lunar exploration program, namely, (a) astronaut on foot, (b) use of the Lunar Scientific Survey Module (LSSM), and (c) use of the Lunar Flying Vehicle, are examined as to their range, capabilities, and limitations. Certain inherent advantages are uniquely associated with the Lunar Flying Vehicle and it is suggested that this should be given serious consideration.

[redacted]

3. Liquid Cooled Undergarment
4. Thermal Meteoroid Garment
5. Extravehicular Accessories (e.g., boots, gloves, visor)

The EMU provides up to 4 hours of continuous separation (3 hours of nominal mission and 1 hour of contingency) from the spacecraft for each excursion before it has to be recharged (which takes approximately one hour).

The Apollo Portable Life Support System (PLSS) currently weighs approximately 65 pounds* when fully charged and is carried on the astronaut's back. This unit contains one pound of oxygen (.93 pound usable) stored at 900 psi and provides oxygen and CO_2 control for respiration and cooling for average work rates of 1,600 Btu/hr. It can accommodate peak work rates of up to 2,000 Btu/hr for periods of up to 10 minutes and the total capacity for cooling is approximately 4,800 Btu. The current estimate of the use rate of oxygen is approximately 0.26 lb/hr at a work rate of 1,600 Btu/hr. Usage at other work rates is assumed to be proportionate. The PLSS unit also provides Pressure Garment Assembly pressurization of 3.85 $\pm$ 0.15 psia in the nominal mode. The unit can handle external heat leaks of 250 Btu/hr in (for day EVA) and 350 Btu/hr out (for night EVA). For metabolic heat removal, cold water is circulated at the rate of 4 lbs/min from the PLSS through tubes in direct contact with the skin. The gas ventilation loop removes CO_2, moisture, provides a continuous flow of oxygen, and controls total pressure. The PLSS unit has a two-way voice communication system and ten channels of telemetry for data transmission to Earth. Telemetered measurements will permit an assessment of suit pressure, H_2O quantity, oxygen supply, power use rate, thermal performance, and critical medical parameters.

A redundant oxygen supply system,** separate from the PLSS, is also provided. This is a 3.5 lb unit which contains 0.2 lb of oxygen stored at 7,500 psi. This unit is a safeguard against failures associated with the following:

1. High suit leak
2. Low suit pressure

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*The new weight estimate for the PLSS unit is approximately 70-75 lbs.

**The emergency O_2 system is under study to provide possibly 30 minutes supply at purge flow rate of 8 lb/hr. Total weight including 4 lbs usuable oxygen will be approximately 25-30 lbs.

3. Fan
4. O_2 pressure regulator
5. LiOH
6. Coolant pump
7. Sublimator
8. Oxygen tank
9. Gas line
10. Liquid line
11. Water reservoir

The emergency oxygen supply system will provide approximately 6 minutes of additional time at a use rate of 2 lb/hr during the purge mode. This unit is not rechargeable.

The Pressure Garment Assembly consists of the basic garment, helmet, boots, and gloves. The suit provides pressure protection with sufficient mobility(1) to accomplish the early lunar missions on foot. The urine collection bag is identical to the Gemini configuration except for minor modification. The EMU provides for fecal collection but no disposal during the pressurized suit mode.

The liquid cooled garment is worn under the suit next to the skin. The PLSS circulates water as a coolant through polyvinyl chloride tubing sewn into the garment (in direct contact with the skin).

The thermal-meteoroid garment is worn over the entire pressure garment to protect the suit from cuts, abrasions, and penetration of meteoroid particles traveling at velocities up to 30 km/sec. It also provides passive thermal control. The present plans are to integrate the thermal-meteoroid garment with the pressure garment assembly.

As is apparent, the Apollo suit requires a lot of metabolic energy to operate. The tests conducted to date indicate that metabolic expenditure for walking in the pressurized suit will require up to twice as much energy as that of the unpressurized suit under one g. The data also indicate that metabolic expenditure for walking will be reduced up to 50% due to 1/6 g lunar environment*. From these data it is expected that the astronaut should be able to travel at the rate of approximately 3 km/hr without any undue thermal stress.

Based on the present design configuration and failure mode of the EMU, the astronaut at no time can walk more than twenty-six minutes[1] away (approximately 1 km) from the spacecraft before he has to start walking back. This is based on the nominal use rate to this point, which is 0.113 lb of oxygen at a use rate of 0.26 lb/hr, and the emergency use rate of 2 lb/hr, which is 0.867 lb of oxygen for twenty-six minutes. This adds up to 0.98 lb of oxygen and the total usable oxygen suuply is 1.13 lb. This leaves 0.15 lb of oxygen to get out of and into the spacecraft; current estimates indicate that this may not be enough and thus the 1 km range may be further reduced. Based on the above criteria, the mission envelope is shown in Figure 1, adapted from Reference 1. The astronaut must stay within this envelope. If he works harder or has a greater suit leakage rate, the envelope is further reduced. The early Apollo missions will have to conform to this envelope.

In some of the recent 1/6 g simulation tests, it has been observed that the astronaut may experience a great deal of difficulty in maintaining his balance, and this may put a further limitation on the distance the astronaut may be able to walk away from the spacecraft. Some of the recent underwater studies conducted by General Electric in a 1/6 g simulation substantiate this problem and recommend that the astronaut at all times must be provided with at least one staff to aid in maintaining his balance on the lunar surface. Their studies indicate that the astronaut may not be able to deploy the ALSEP package on the earlier Apollo missions as presently conceived.

During the lunar AAP phase, it is anticipated that the hard suit will be available. Currently, there is very little information available on this except that it will be less vulnerable to abrasion and puncture due to its proposed metal and plastic construction. The suit will be designed to have a very low leakage rate, will be lighter, and will provide increased mobility because the joints are designed to allow bending without volume change.

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*This is based on MSC data and is controversial. Roth (NASA SP-84, Bioenergetics of Space Suits for Lunar Exploration, by E. M.Roth, 1966) anticipates a 34% increase over 1 g levels. We will know more about this after the first Apollo flight.

Lunar Scientific Survey Module (LSSM)

The Lunar Scientific Survey Module for lunar surface mobility is expected to be available during the post Apollo period. The proposed basic configuration of the LSSM vehicle is omitted for the purposes of this memorandum; however, some of the significant capabilities of this roving vehicle are planned to include a gross payload capability of approximately 1,000 pounds, an approximate range of 8 km and an average approximate speed of 4 km/hr or more. The LSSM will have provision to carry two spare PLSS units; theoretically this will provide 9 hours of continuous astronaut separation from the spacecraft.

In order to determine the enhanced capability and limitations on the LSSM and astronaut, the following observations may be made based on a single failure mode analysis (Fig. 2):

1. If the LSSM vehicle fails on any excursion, the astronaut will be capable of returning to the spacecraft from a range of 8 km provided a fully charged PLSS unit is available (an astronaut is assumed capable of traveling at the rate of approximately 3 km/hr, and a PLSS unit has 3 hours of nominal excursion capability). Thus, this failure mode dictates that from a distance of 8 km the astronaut should start back at the end of six hours of separation from the spacecraft.

2. If the PLSS unit fails (considering the worst case where one PLSS unit is completely lost) the astronaut will be capable of returning to the spacecraft in the LSSM vehicle provided he has a minimum of 2 hours of separation capability left in his PLSS unit (LSSM average speed 4 km/hr). This failure mode dictates that from a distance of 8 km the astronaut should start back at the end of 4 hours of separation from the spacecraft.

Since the second failure mode is overriding, the astronaut in all cases will have to plan on starting the return trip from a distance of 8 km at the end of the 4th hour of separation from the spacecraft. Thus, with the availability of the LSSM vehicle, the astronaut range capability on the lunar surface may be increased by approximately one order of magnitude, but the staytime at maximum range is only 2 hours (4 hours less 2 hours travel-out time).

Lunar Flying Vehicle (LFV)

One of the most promising means of lunar mobility is by the use of the Lunar Flying Vehicle. This type of vehicle will be quite attractive from the standpoint of astronaut safety, range, minimum trip time and maximum scientific return. Also, the flying vehicle will provide capability to investigate remote areas which otherwise would be inaccessible to types of surface mobility aid such as LSSM or by walking.

Various types of manned flying systems have been proposed by Bell Aerosystems, depending on the objectives and strategy of the lunar exploration program and modes of payload delivery capabilities on the lunar surface.

One of the proposed flying units(2) can carry two pressure suited astronauts for a distance of 15 miles out and return. Up to 300 pounds of payload may be carried instead of the second astronaut.

However, from the standpoint of payload limitations (application with a single launch vehicle), cost, development time, and early applicability, a one-man flying unit may be more fruitful. Some of the significant parameters for such a vehicle as proposed by Bell Aerosystems are described below:

Dry weight plus residuals	146 lb
Usable propellant capacity	273 lb
Astronaut weight	295 lb
I_{sp}	285 sec
Maximum payload	200 lb

The LFV (Figure 3) utilizes two rocket nozzles which are gimbal mounted and controlled directly by operator hand, arm, and shoulder motions. The propulsion system utilizes LM propellants. Helium is stored in the two pressure vessels on either side of propellant tanks and used as the pressurant to expel the liquid propellants. The vehicle uses visual/manual guidance techniques and a timer is provided for trajectory control and guidance. Figure 4 shows round trip performance of LFV when carrying 50 lbs of payload in addition to the astronaut, with refueling for a total of 1,000 lbs of propellant. Figure 5 shows the amount of propellant required to deliver a payload and return with no payload. Figure 6 shows the amount of propellant required to accomplish a single sortie including a number of stops.

The example cited above is for illustrative purposes and modifications will be required based on mission objectives and design criteria. For example, provision for astronaut safety against impingement of hot gases from nozzle exhaust will be required. Other modifications may include increased payload capability to 300 lbs so that the vehicle may be used for rescue purposes; better guidance techniques other than those proposed may also be required.

The limitations on the use of the Lunar Flying Vehicle may be reasoned on similar lines as in the cases of astronaut excursions on foot and by the use of LSSM vehicle. In the case of LFV failure, the astronaut will have to be rescued by a second LFV mission. For the case of PLSS unit failure, either the astronaut will have to be provided with a spare PLSS unit which will be a part of the payload, or the staytime at a remote site would have to be limited to allow time to fly back on the remaining oxygen, in the emergency mode. Since flight times in the LFV are limited to a very few minutes, range is virtually unlimited by contingency considerations.

III. CONCLUSIONS

The three forms of lunar mobility systems, namely, astronaut on foot, use of the LSSM vehicle, and use of the Lunar Flying Vehicle, are briefly discussed along with their range, capabilities and limitations. While the merits of each form either individually or jointly are dependent upon the objectives of the lunar exploration program, certain inherent advantages are associated with the use of the Lunar Flying Vehicle and it is suggested that it should be given serious consideration.

R. Sehgal

R. Sehgal

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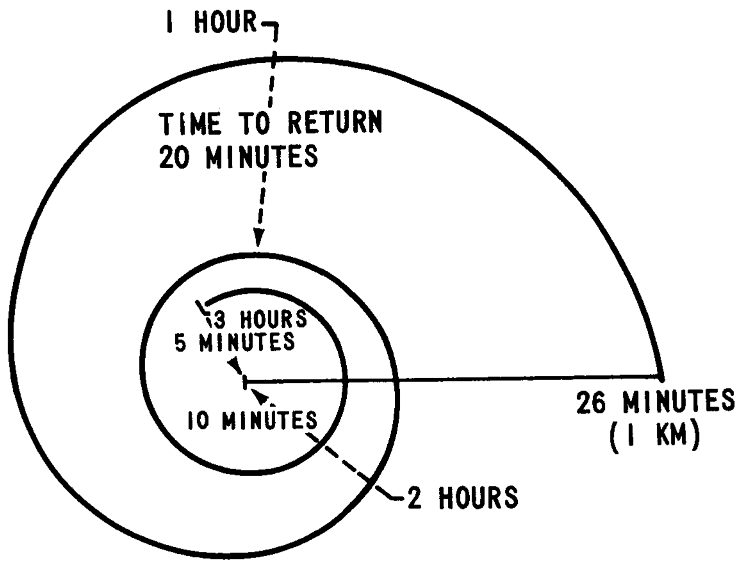
Attachments
References
Figures 1 - 6

REFERENCES

1. "Extravehicular Mobility Unit Operations," by W. C. Kincaide, presented at the Apollo Lunar Landing Mission Symposium, June 25-27, 1966, at MSC, Houston, Texas.

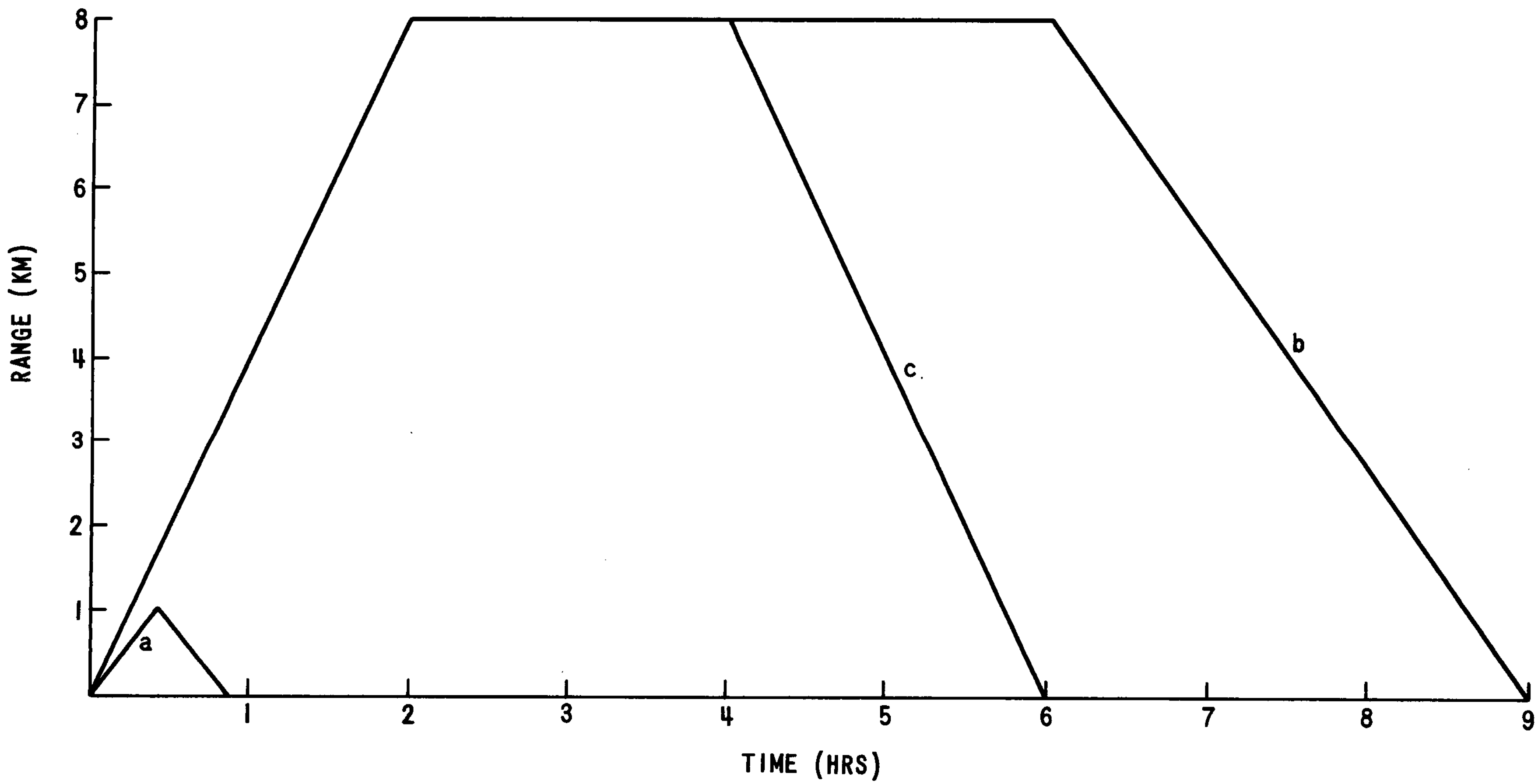
2. "Lunar Flying Unit Mission Applications," by Bell Aerosystems, Report No. 72 84-95 3001, December, 1966.



RANGE LIMITATION RESULTING FROM THE
OXYGEN AVAILABLE FOR EMERGENCY USE

FIGURE I
(REFERENCE I)

RANGE VS EXCURSION TIME
BASED ON SINGLE FAILURE MODE



a. EXCURSION ON FOOT BASED ON EMU FAILURE (NO SPARE PLSS UNIT)

b. EXCURSION WITH LSSM BASED ON VEHICLE FAILURE (LSSM HAS 2 SPARE PLSS UNITS)

c. EXCURSION WITH LSSM BASED ON SINGLE PLSS UNIT FAILURE (LSSM HAS 2 SPARE PLSS UNITS)

FIGURE 2

FIGURE 3

(REFERENCE 2)

LUNAR FLYING UNIT
ROUND TRIP PERFORMANCE

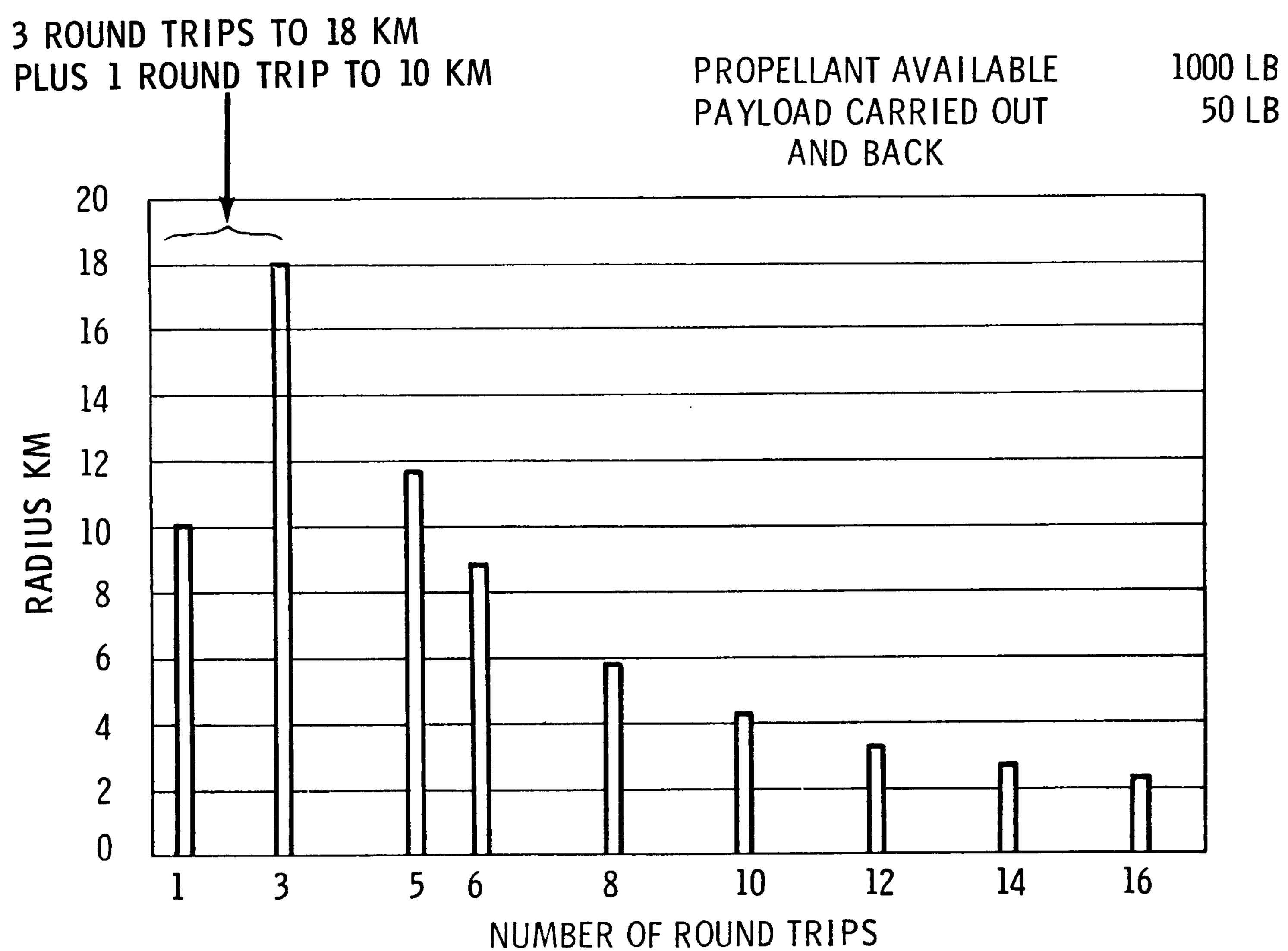


FIGURE 4

(REFERENCE 2)

LFU PAYLOAD DELIVERY CAPABILITY

PAYLOAD CARRIED OUT - RETURN WITH NO PAYLOAD

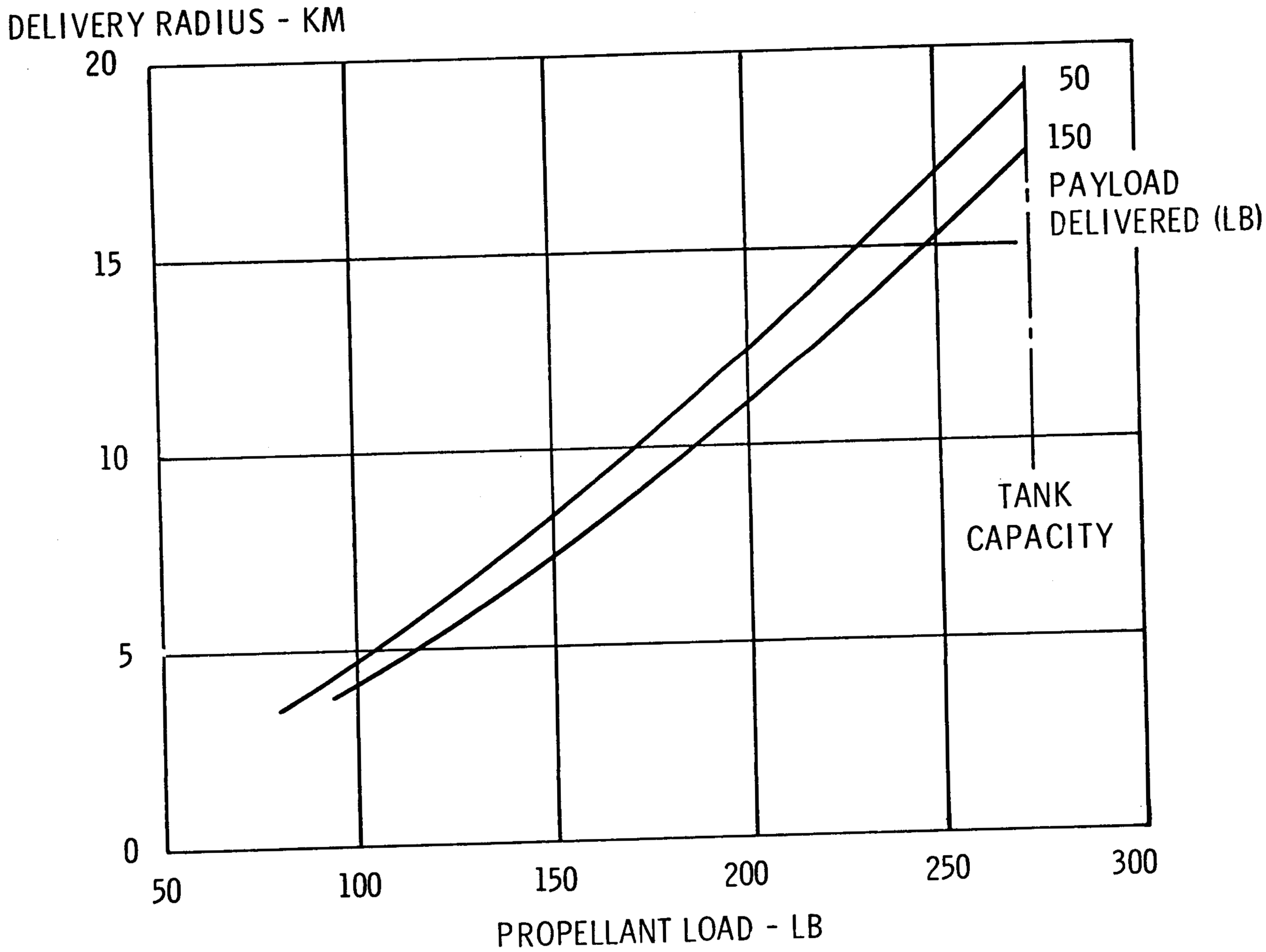


FIGURE 5

(REFERENCE 2)

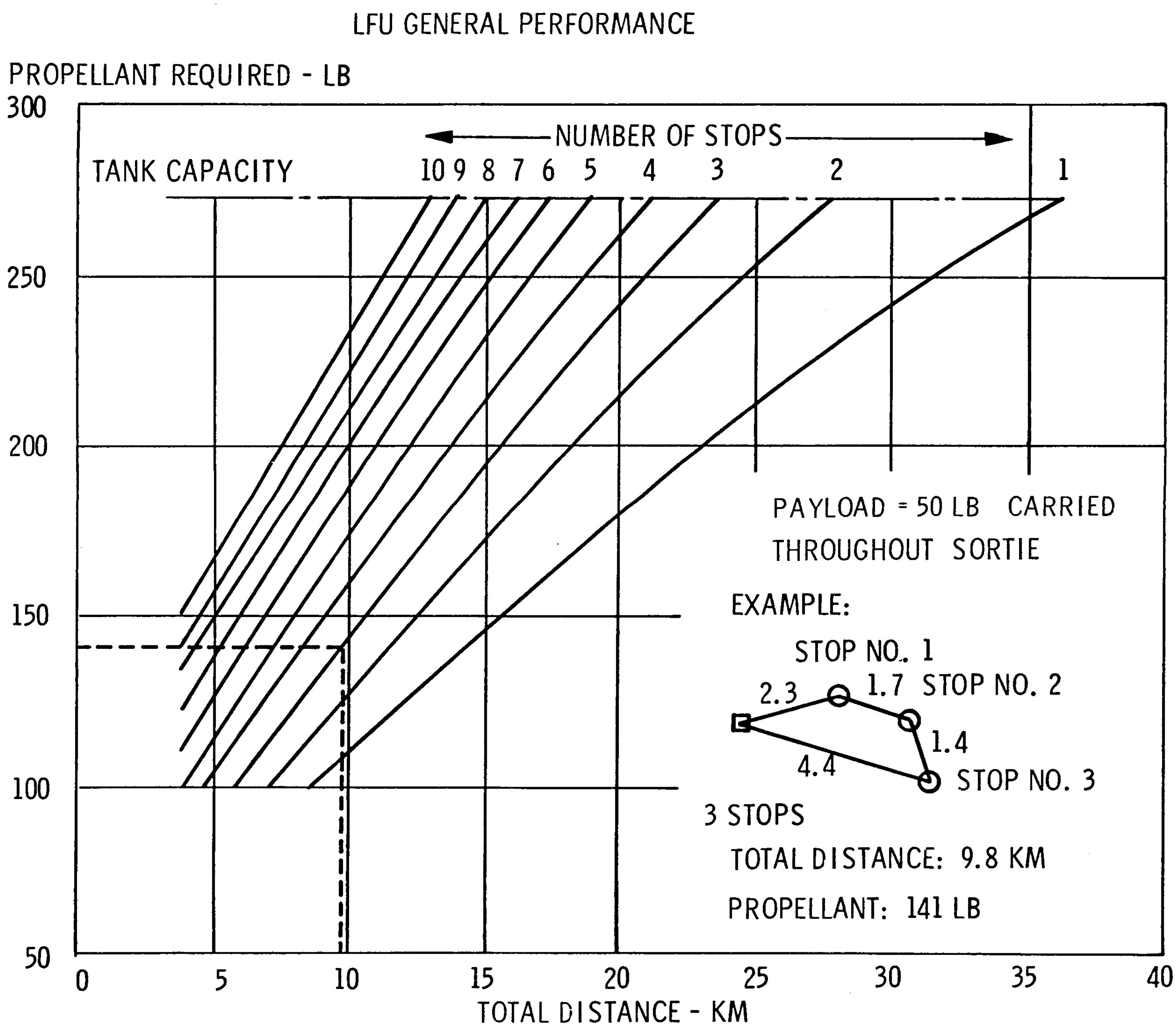


FIGURE 6

(REFERENCE 2)

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